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Precision Directional Coupler For Matching Measurements

Directional couplers are frequently required in high frequency measurement technology. They are used, not only in standing wave measurement equipment, but also in high quality test rigs and network analysers. A directional coupler is described below, it has high directivity and can be used from approximately 120MHz up to 1,500MHz.

1. Introduction

If we want to carry out wobbled matching measurements, then, among other things, we need a good directional coupler with high directivity. The directivity is the measurement of how well the directional coupler can distinguish the forward transmission from the reverse transmission.

To be able to carry out meaningful measurements, even on high quality components and good DIY circuits, the directivity should be as high as possible, exceeding 30dB. However, as industrially manufactured directional couplers are used in high tech equipment, the price of a new one is too high for most radio amateurs, and they are scarcely found on the surplus market.

There are numerous publications dealing with the construction of directional couplers, but some of them are designed for simple applications only, e.g. for SWR meters, the directivity is frequently only 25dB.

2. Requirements

If you want to build a directional coupler with a high directivity, then the following points must be given consideration during construction:

- Maintenance of 50Ω impedance in the main and secondary lines
- Precise 50Ω termination for all lines
- Discontinuities should be as slight as possible where there is a transition from the lines onto the coaxial connectors and the dummy load
- Trimming option for secondary line for maximum directivity

Experiments with coupled semi-rigid lines have already provided usable results, but they have not led to the desired directivity of 40dB. Precise impedance can be achieved using the solid sheath cable, but it is badly influenced by the long windows (λ/4).

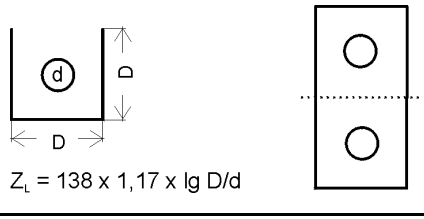

Fig. 1: U-shaped coaxial line.

On the basis of these experiments, attempts were made to find a way to produce two coupled lines running parallel, with 50Ω impedance.

Here are some reflections on this. A 50Ω line can consist of a round external conductor with a round internal conductor, or of a square external conductor with a round internal conductor. There is also a formula for calculating a 50Ω line that consists of a U shaped external conductor with a round internal conductor:

ZL = 138 x 1.17 x Ig D/d

If we use two of these U shaped coaxial lines and join them at the open sides, then we obtain two coupled 50Ω lines (Fig. 1).

This led to the directional coupler illustrated in Fig. 2, with a directivity exceeding 45dB together with a good band width. The measurement of the forward and reverse transmission in the frequency range of 40MHz to 1,500MHz was carried out using a Wiltron network analyser (Fig. 3). The good directivity values of 45 to 48dB can be read off from the measurement curve.

Fig. 4 shows the measurement results up to 3GHz, which were measured using a Rohde & Schwarz network analyser. Here too, we can see the extremely high

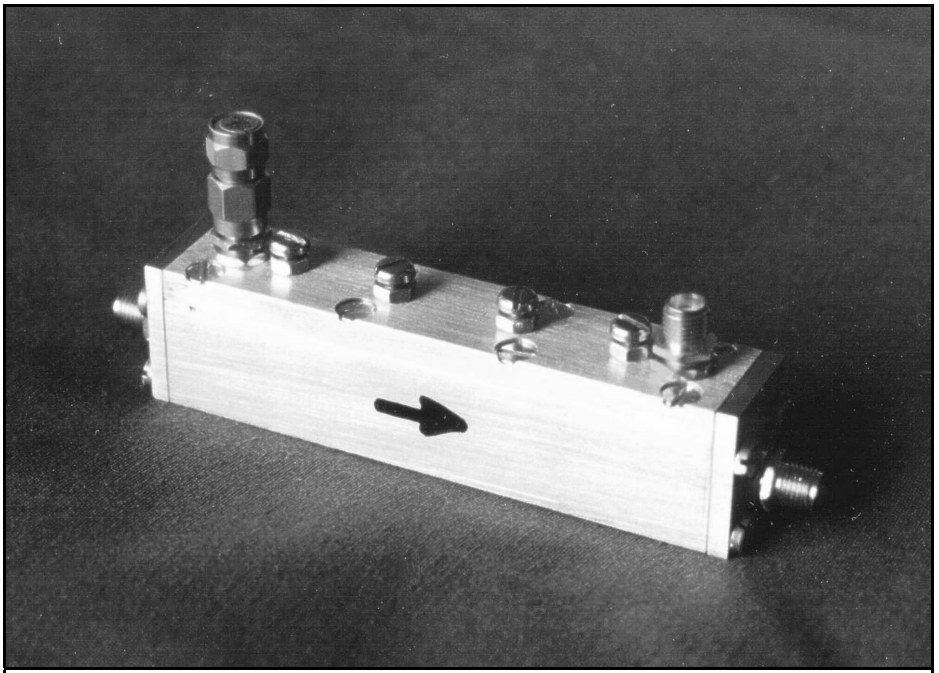

Fig. 2: Ready-to-operate specimen of directional coupler, made from brass, with SMA jacks for main and secondary branches and with calibration screws in cover.

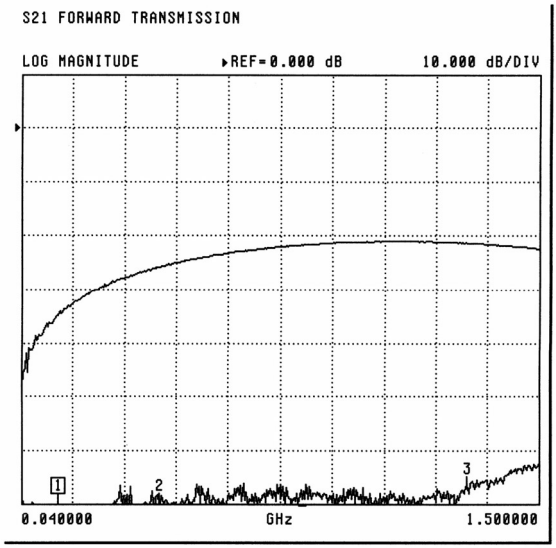

Fig. 3: Measurement of forward and reverse transmission in range between 40 and 1,500 MHz shows a directivity of approximately 45dB.

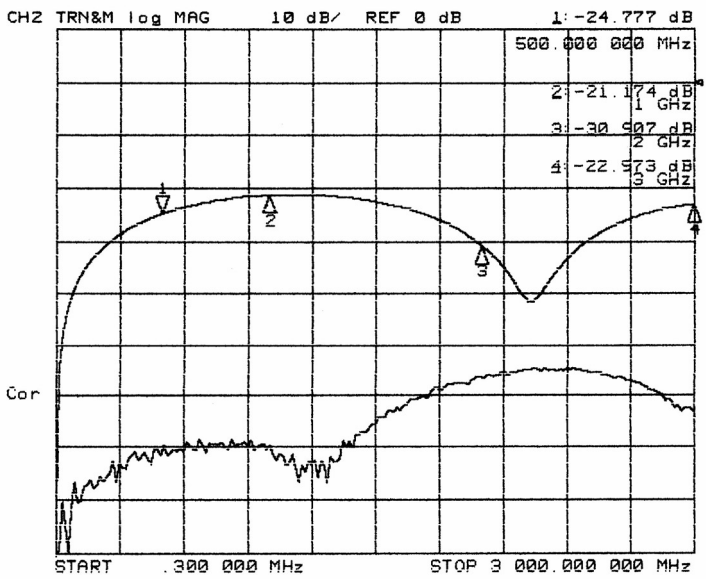

Fig. 4: Measurement results up to 3 Ghz.

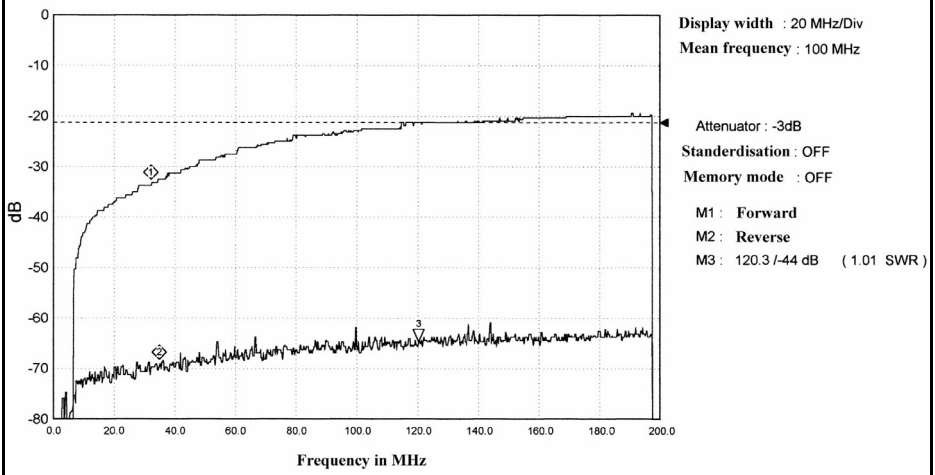

Fig. 5: Good directivity (44db at 120MHz) even in lower frequency range to 200 MHz.

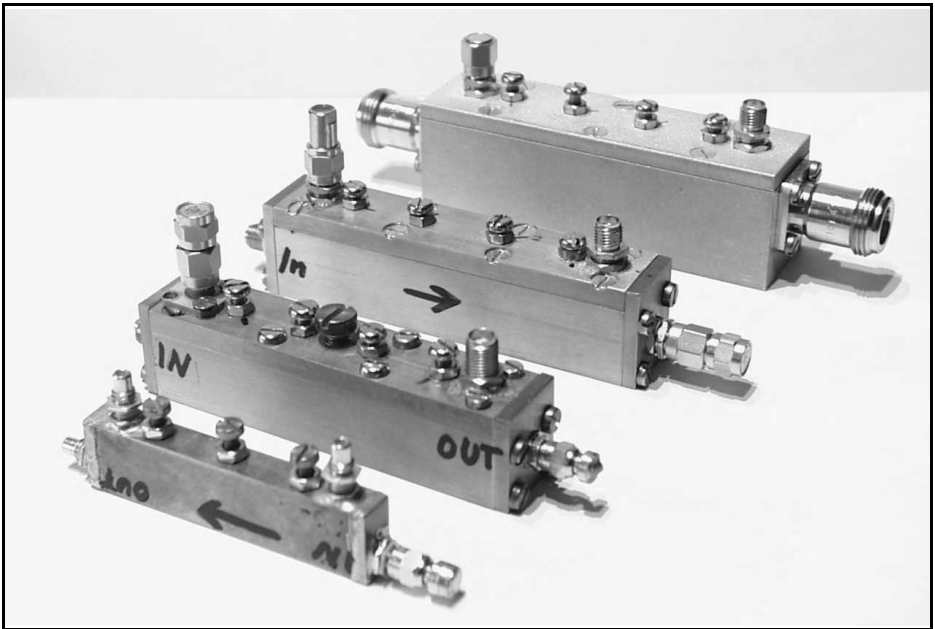

Fig. 6: Specimen assemblies of various directional couplers in different sizes, with SMA or N jacks in the main branch.

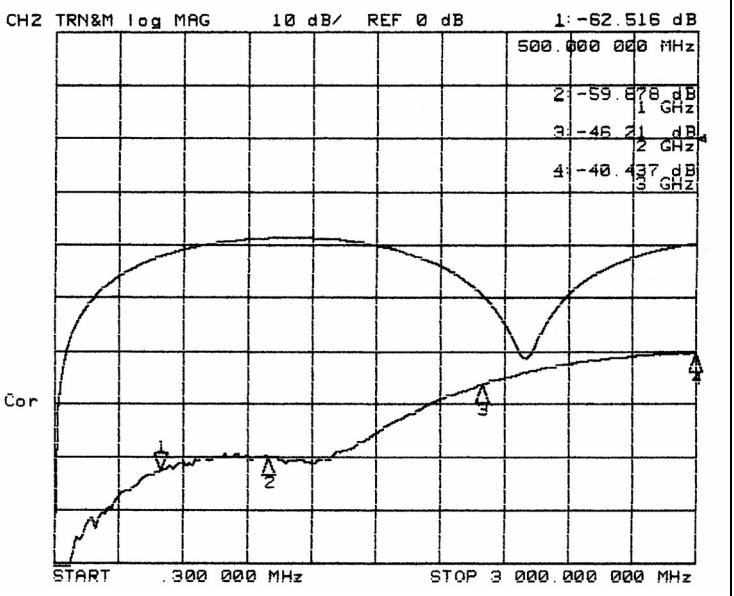

Fig. 7: The measurement curves show the somewhat poorer values when N jacks are used.

directivity levels, which go all the way up to 1,500MHz. If calibrated for narrow band, even higher values of directivity could be attained, exceeding 50dB (!).

Fig. 5 shows the forward and reverse transmission for the directional coupler in the lower frequency range up to 200MHz. It can be seen from this that the directional coupler, in conjunction with sensitive wobble systems, can be used with a good directivity even at low frequencies (44dB at 120MHz).

Several directional couplers with various connection jacks were assembled in accordance with this concept (Fig. 6). It became clear from this how important it is to use high quality coaxial jacks. It is extremely important to have as few rf discontinuities as possible in the transition onto the coaxial jacks. The best results were attained with good SMA and SMC jacks. Somewhat lower directivity values were attained from assemblies using N jacks (Fig. 7). So only precision jacks with small flanges from reputable manufacturers should be used.

If we move into directivity values exceeding 30dB, we likewise need a high value 50Ω termination on the secondary and main lines. It is best if two equal dummy loads are used. You can not do without high quality industrially produced dummy loads but they can be obtained at acceptable prices.

3.

Assembly

The mechanical components of the directional coupler are all made of brass (Fig. 8). The main body consists of an 18mm. x 18mm. square bar with a milled grove 6.1mm. wide and 12.2 mm deep. An 18mm. x 5mm. piece of brass flat material is used as a cover. Incorporated here, among other things, are 4 tuning screws (M3), to tune the secondary line.

The side components are made from 3mm. thick brass. The cover and side components are each screwed onto the

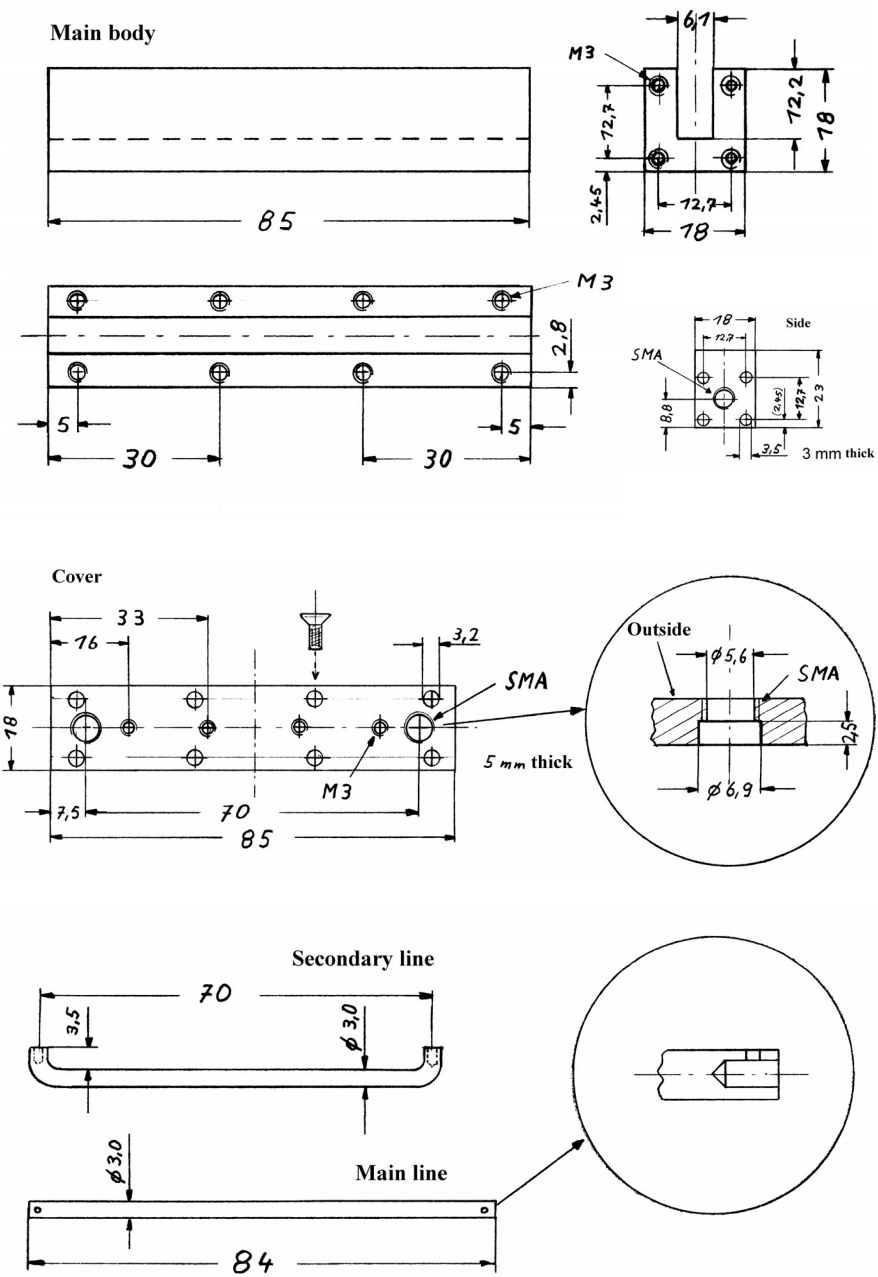

Fig 8 : Details of the mechanical components.

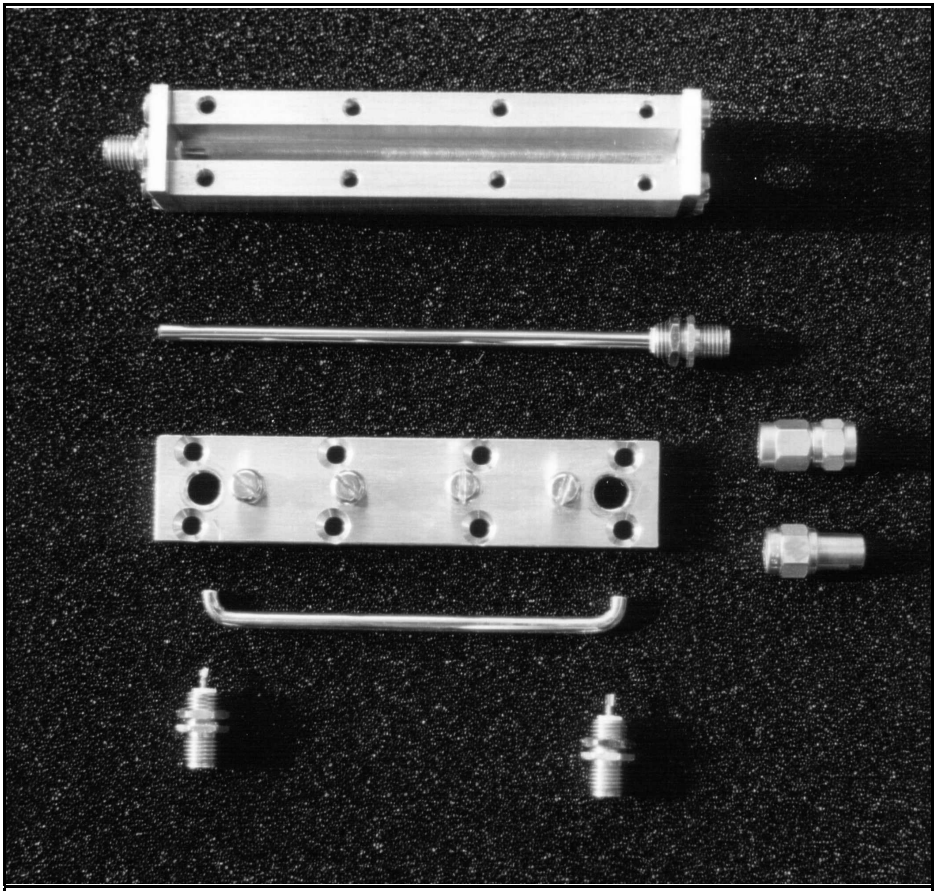

Fig. 9: Individual components of directional coupler: 18 x 18 mm. coupler, with side components, main coupling line made from round bars, cover with tuning screws and holes for SMA jacks, secondary coupling line and SMA panel jacks.

main body with M3 brass screws.

The internal conductors of the main and secondary lines are each made from 3mm. round pieces of brass. Small holes at the ends support the internal conductor of the SMA jack. The bore diameter is dependent on the type of the jack used. A 1mm. transverse hole is used to improve soldering.

The dimensions and units are shown on the drawings shown in Fig 8. The two internal conductors should be polished, to reduce skin effect.

A thread is cut in the cover and in each side component for the SMA jacks. These threads are described as ¼" 36 UNS-2A. But it is difficult to get hold of taps with this thread. A ¼" 32 NEF tap can be used for short threads. These can be obtained in many model shops, since this is the thread size for heater plugs in model glow plug engines. Fig. 10 shows the directional coupler when opened.

3.1. Coaxial jacks

Quality SMA single hole jacks are used as connecting jacks. In order to keep the

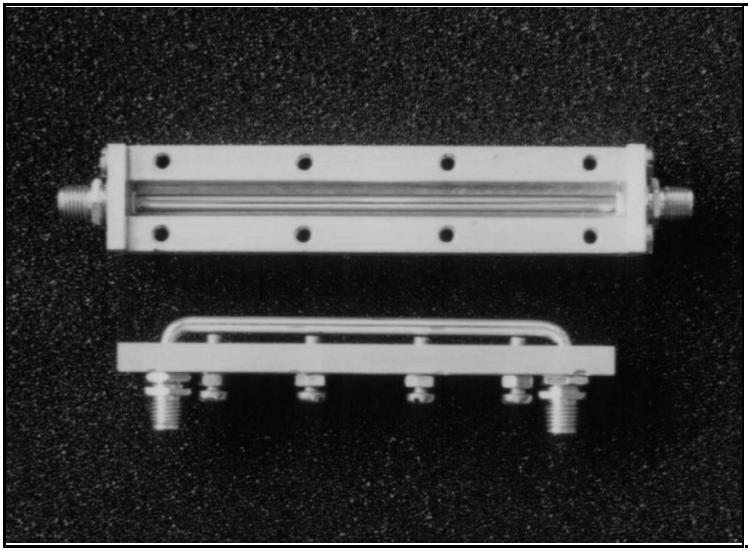

Fig. 10: The fully assembled directional coupler opened up; the tuning screws in the cover can be easily recognised.

rf discontinuities as small as possible, the Teflon inserts, which project at the rear end of the jacks, are shortened to 0.7mm. This compensates for the discontinuities that arise during the transition from the 3mm. thick internal conductor of the directional coupler to the thinner internal conductor of the SMA jack (Fig. 11).

3.2. Final assembly

Once all the components have been manufactured and matched, the main body is assembled, with the side components and the straight internal conductor of the main line. The precise position of the internal conductor can be aligned again while the side components are being screwed on. The four tuning screws must be filed flat before they are fastened in the cover with a lock nut.

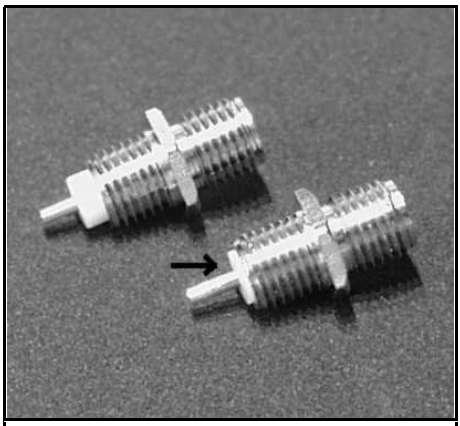

Fig. 11: SMA jacks with unshortened (top) and shortened Teflon edge (below).

The curved internal conductor of the secondary line is fastened to the cover with the two SMA jacks. A guide dimension for the distance from the lower edge of the internal conductor to the cover is 5mm. (see Fig. 12).

The distance between the two coupling lines can be adjusted, depending on how far you screw the two SMA jacks into the cover. This influences the coupling. The best alignment was obtained with a forward transmission of approximately 20dB at 1,200MHz. The SMA jacks are fixed externally using lock nuts.

With this construction it is possible to alter the distance of the coupling lines, even after assembly. Arranging the lines at an angle is also possible.

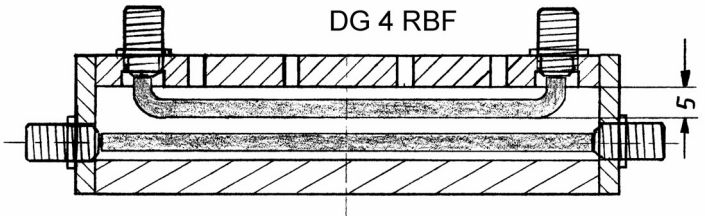

Fig. 12: Details for assembly of body, cover, side components and coupling lines.

4. Calibration

The fully assembled directional coupler is best calibrated with the wobble system with which it is to be used. But calibration can also often be carried out using a fixed signal source (radio equipment) and a sensitive mW meter.

Calibration is carried out with the 4 trimming screws at the best directivity, i.e. with minimum reflection and a dummy load of precisely 50Ω.

In order to guarantee a broad band calibration, the directional coupler should be calibrated in at least one lower and one upper frequency range. A broad band calibration can naturally be carried out most easily using a wobble system.

5. Range of application

Directional couplers are designed, in particular, for matching measurements in conjunction with wobble measurement systems. The directional coupler is very suitable, in conjunction with the rf synthesiser, up to 1,450MHz [2], for spectrum analysers with tracking generators or for scalar network analysers in frequency ranges from 140MHz to 1,500MHz.

This directional coupler concept can be modified and assembled for other frequency ranges by changing the length.

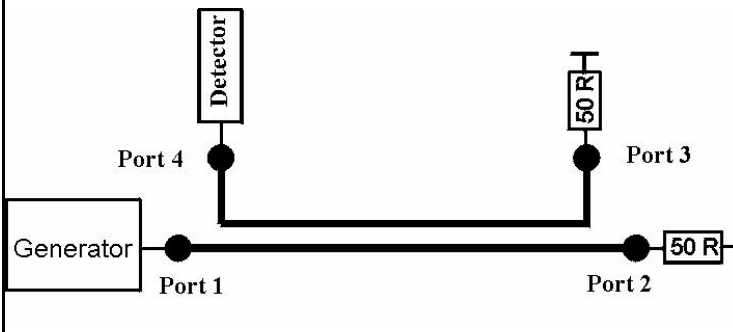

Fig. 13: Measuring rig for measurement of forward transmission:

Generator at port 1, detector at port 4, port 2 and port 3 terminated with 50Ω.

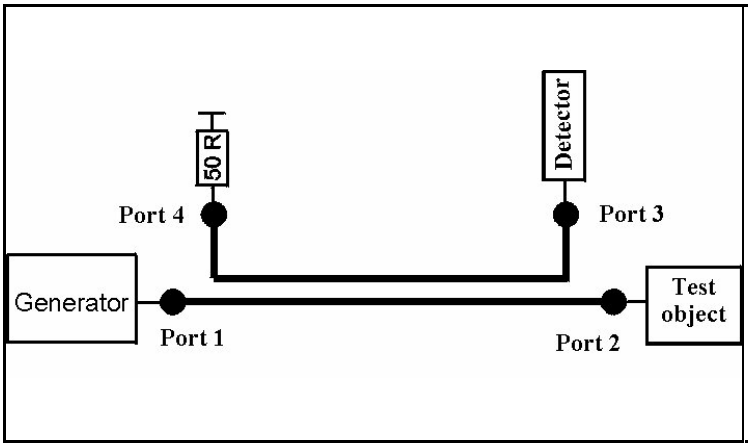

Fig. 13: Measuring rig for measurement of reverse transmission (return loss):

Generator at port 1, test object at port 2, detector at port 3 and port 4 terminated with 50Ω.

6.

Set-up of measuring instruments

First the forward transmission curve is determined and stored. To this end, port 2 is terminated with a 50Ω dummy load and the detector is connected to port 4 (see Fig. 13). The curve determined in this way is the start point for the subsequent reflection measurement.

To measure the reverse transmission, the detector connected to port 3 and the test object is connected directly to port 2 (Fig. 13). The difference between the forward transmission and the reverse transmission can then be used for calibrating the test object.

7.

Literature

[1]Carsten Vieland, DJ4GC Microwave directional coupler with high forward / reverse ratio made from semi-rigid lines, VHF Communications 1992/3 pp 130 - 139

[2] Bernd Kaa, DG4RBF, HF synthesiser up to 1,450MHz, VHF Communications 1998/2 pp 103 - 121 and 1998/3 pp 159 - 181